Geochemistry of Surface Water and Groundwater on the Campus of The Ohio State University

Senior Thesis

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By

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Abstract

This study determined the elemental and isotopic composition and origin of the water that is present in Mirror Lake, the Olentangy River, and the groundwater found on the south campus of The Ohio State University and investigated potential surface water and groundwater interaction. Samples were collected of local precipitation, Mirror Lake, the Olentangy River, and south campus well waters from October 2009 to May 2010. Samples obtained during the Autumn of 2009 have also been analyzed for nutrient (nitrogen and phosphorus) concentrations. The Olentangy River waters have much higher nitrate concentrations than Mirror Lake, with the groundwater being of intermediate concentration. Nitrogen is an indicator of anthropogenic activities influencing the chemical composition of natural waters (Rakowsky, 2000). Total nitrogen was highest in the river, reflecting drainage from agriculturally dominated land north of Columbus. The highest total phosphorus was found in the groundwaters. The highest dissolved silica levels were observed in the groundwaters, indicating that these waters have undergone more extensive silicate mineral weathering than the other waters. Stable isotope ratios of $^{18}O/^{16}O$ and $^{3}H/^{2}H$ were also analyzed in these samples, and the data indicated a much larger variation in the surface water than in the groundwater. Chloride concentrations were most variable in the Olentangy and highest in the South Campus Well (Gardner and Carey, 2004). This could be a result of road and sidewalk salt running off into the groundwater. Potassium concentrations were nearly constant both annually and between the samples. Calcium concentrations were highest in the South Campus well, possibly a result of water-rock interaction between the groundwater and Columbus Limestone underlying the sample location. Concentrations of sodium were significantly higher in both the South Campus Well and the Olentangy River than in Mirror Lake. This could be a result of road and sidewalk salt runoff.

Acknowledgments

Thank you to Dr. Berry Lyons, research advisor. I especially thank Kathy Welch, Dr. Sue Welch, and Deb Leslie for help with analysis and interpretation. Thanks to Dr. Steve Goldsmith and Dr. Scott Bair for help with sample and data collection.

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Introduction

Groundwater – surface water interaction is a fundamental process in hydrogeology. For example, base flow in streams is supported by groundwater input and many lakes either recharge or obtain water from groundwater discharging to the surface (Winter et al., 1998). The purpose of this study was to investigate surface water and groundwater interaction between Mirror Lake, the Olentangy River, and the groundwater found on the south campus of The Ohio State University by determining their elemental and isotopic composition. Chemical and isotopic differences among the different sources of water were evaluated and used to help explain the geochemical processes occurring at each location. The major question in this study was whether or not these three different types of waters are hydrologically connected. If these waters are hydrologically connected, then they should have similar geochemical compositions.

Sampling Area

Samples were collected monthly from October 2009 to May 2010 from three locations on the campus of The Ohio State University: a well on the South Oval (from here on referred to as the South Campus Well), Mirror Lake, and the Olentangy River (Figure 1). The South Campus Well draws water from the Columbus Limestone (Table 1). It is located at 39˚59'51" N, 083˚00'45" W, south of Mendenhall Laboratory, and north of Enarson Hall. The depth of the well is 5.6 meters, and the well's water level was less than two meters in depth each time it was sampled. Mirror Lake was sampled at 39˚59'54" N, 083˚00'50" W, at the eastern end of the lake, south of the man made spring (Herrick, 1984). The Olentangy River runs through glacial till that was deposited by Wisconsinan-age glaciers (Ohio Division of Geological Survey, 2005) and its sampling location is 40˚00'00" N, 083˚01'24" W, west of Drake Performance and Event Center, north of the bridge that extends over the Olentangy River from Drake Performance and Event

Center to Sisson Hall. Precipitation was collected in February 2010 at Byrd Polar Laboratory on West Campus (40˚00'12" N, 083˚02'19" W).

Geologic Setting

The sampling locations for this survey, while focused on the Campus of The Ohio State University, are influenced by the geology of the Upper and Middle Olentangy Watershed. While an extensive discussion of the lithologies found in Central Ohio is not within the scope of this paper, the lithologies present in the Olentangy Watershed are presented in stratigraphic order from youngest to oldest in Figure 3. The Upper Olentangy River Sub-Basin, also known as the Upper Geological Region of the Olentangy, consists of portions of Richland, Crawford, Marion, Morrow, and Delaware counties. The Olentangy River incises the till plain no more than 6-9 meters over this region. Glacial till is 9 to 18 meters thick on this region of the Olentangy. Both corn and soybeans are presently grown here. Conventional farming processes lead to high P and N runoff from fields. The Middle Geologic Region extends from the Delaware Dam, located north of the city of Delaware to the County line between Delaware and Franklin County. Over the Middle Geologic Region, the Olentangy River flows over the Delaware Limestone as well as sand, gravel, and cobbles derived from local sources. Glacial erratics, quartzite, and gneiss transported by Wisconsinan-age glaciers from Southern Ontario are also present (FLOW, 2003, Ohio Division of Geological Survey, 2005). See glacial map of Ohio in figure 2. The Lower Geologic Region flows from the county line that separates Delaware and Franklin County to where the Olentangy River and the Scioto River converge in Columbus, Ohio. The Lower Geologic Region of the Olentangy River is broader and deeper than the Upper and Middle Geological Regions of the Olentangy. There is more silty alluvium, and more glacial outwash sand and alluvium present in this stretch of the Olentangy River. These glacial deposits reach up to 37 meters in depth, and are over 30 meters deep below the campus of The Ohio State University. North of the 5th Avenue Bridge there is a 2.4 meter high concrete low-head dam that causes the Olentangy River pool from the location of the bridge upstream to the Dodridge Street Bridge. Aquatic vegetation is present here, along with silt and clay on riverbed, yet it lacks naturally occurring riffles on gravel substrates. See Table 1 for a brief description of bedrock formations in the surrounding area of the Olentangy River (FLOW, 2005). See Figure 3 for a generalized cross section of sample area. Mirror Lake is encased in cement, and it lies on top of Quaternary Glacial deposits. The South Campus Well is a monitoring well that penetrates Quaternary Glacial Deposits and draws water from the Columbus Limestone Formation.

Methods

Sampling Methods

Samples were collected from the South Campus Well, Mirror Lake, the Olentangy, during October, November, January, March, and April of the 2009-2010 academic year. Precipitation was collected in January 2010. A 4.22 cm diameter, 0.91 m long bailer, made of transparent PVC was used to collect all surface water and groundwater samples. The bailer was tied to a 0.48 cm diameter solid braided polyester rope. The bailer was rinsed three times with water to be sampled before pouring sample into bottle, and thoroughly rinsed with deionized water after each trip to the field. South Campus Well was bailed at least 3 times before taking samples. The recharge rate was rapid, and bailing the well dry and acquiring a sample of entirely recharged groundwater was not possible. Samples were collected in LDPE Nalgene liter bottles that had been rinsed in the laboratory three times with deionized water and then bagged in plastic prior to sampling. Bottles were then rinsed with sample 3 times before filling on site. Glass scinitillation vials that were used to collect samples to be analyzed for isotopic composition were rinsed with the sample 3 times before filling on site.

Laboratory Procedures

Surface water and ground water samples were analyzed for Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^{-}, NH_4^{+}, PO_3^{-}, and N-NO_3^{-} concentrations. Samples were filtered through 0.4 μm pore-size Nuclepore polycarbonate membrane filters and then stored in 100 mL LDPE Nalgene bottles that were rinsed 3 times with deionized water until analysis. Alkalinity titrations were done by using a Hach digital titrator, Bromcresol green methyl red indicator, and 0.1 N HCl to titrate 10 mL of each sample three times, and then the three replicates were averaged. Nutrient analyses for surface and ground water were done using a *Skalar SAN*++ Continuous Flow Analyzer (CFA). (For precision of measurements see Table 2). Anion and cation analyses were done using a Dionex DX-120 Ion Chromatograph (for precision of measurements see Table 2). Duplicate samples analyzed for major ions and nutrients show variation below the % difference seen in Precision Chart. Stable isotope data was run on precipitation, surface water and ground water. Isotopic analysis was done using a Picarro WS-CRDS Analyzer for Isotopic Water - Model L1102-I (for precision of measurements see table 3).

Results

All the data from this study are tabulated in Appendix A.

Ion and Nutrient Analysis

The Cl^{-}, K^{+}, Ca^{2+}, N-NO_3^{-}, and Na^{+} concentrations from the South Campus Well, Mirror Lake, and the Olentangy River are found in figures 4,5, and 6. For anion piper diagram see figure 7. For cation piper diagram see figure 8. Figure 7 shows the percentage of Ca^{2+}, Mg^{2+}, and Na^{+}+K^{+}

in the waters of the three sample sites tested. All three waters plotted relatively close together, with the South Campus Well exhibiting higher percentages of Mg^{2+} (30-55%) than the other to waters tested. Mirror Lake showed the least variance in % alkalinity (HCO_3^-) over the sampling period, remaining within a range of 60-70% alkalinity. Cations from chemical weathering due to water rock interactions undergo a chemical reaction; primary mineral + H_2O + CO_2 →secondary mineral + cation + HCO_3^- + dissolved Si^+ (Faure, 1998). This results in waters of different compositions, depending on what primary minerals are interacting with water. Alkalinity is highest in the South Campus Well, and the Olentangy River has the second highest Alkalinity of all three sample sites. Cl^- concentrations in the South Campus Well ranged from 90.1-102.3 mg/L. Cl^- concentrations in Mirror Lake ranged from 31.2-47.2 mg/L. The Cl^- concentrations measured for the Olentangy River spanned 89.02 ± 72.6. The concentration of Cl^- in the Olentangy River in October (55.3 mg/L) and November 2009 (50.3 mg/L) samples were less than half of the Cl^- concentrations measured in March (126.4mg/L) and April (124.1 mg/L) of 2010. All samples taken from selected locations exhibited concentrations of K^+ that stayed nearly constant both annually and between samples. (See appendix A) The groundwater samples taken from the South Campus Well in March 2010 and April 2010 exhibit enrichment in Ca^{2+} with respect to previous samples collected at other times of the study and with respect to the Ca^{2+} concentrations exhibited in Mirror Lake in spring 2010. The concentrations of Ca^{2+} in the samples collected from the South Oval Well in October (72.0 mg/L) and November (73.4 mg/L) were lower than the April and May samples from the South Campus Well, which has Ca^{2+} concentrations of 139.0 mg/L and 121.3 mg/L, respectively. The April Ca^{2+} concentration in Mirror Lake was 28.6 mg/L, and the April Ca^{2+} concentration of the Olentangy River was 93.9 mg/L. Ca^{2+} concentrations stay nearly constant in Mirror Lake, averaging a Ca^{2+} concentration of

26.9 mg/L over the length of the study. The Ca^{2+} concentration increases from 55.3 mg/L to 93.9 mg/L from November to May in the Olentangy. $N\text{-}NO_3^-$ concentrations of Mirror Lake (0.087 ± 0.17 mg/L) and the South Campus Well (0.079 ± 0.37 mg/L) were lower and less variable than the concentration of $N\text{-}NO_3^-$ in the Olentangy River (2.09 ± 2.64 mg/L). Na^+ concentrations in the South Oval Well (35.3 ± 3.07 mg/L) stayed nearly constant throughout survey. Mirror Lake Na^+ concentrations (18.7 ± 9.07 mg/L) fluctuated throughout survey, with lower values in October (14.4 mg/L) and November (14.3 mg/L) than in March (24.8 mg/L) and April (21.3 mg/L). Na^+ concentrations in the Olentangy River rose significantly from November (22.7 mg/L) to March (69.6 mg/L). While the Na^+ and Cl^- concentrations of the South Campus Well and Mirror Lake stayed relatively constant, the concentrations of Na^+ and Cl^- increased significantly from November (50.3 mg/L) to March (126.4 mg/L) in the Olentangy River. Mirror Lake exhibits the highest levels of PO_4^{3-}, with an average concentration of 365.8 µg/L. The average concentration of PO_4^{3-} in the Olentangy was 58.1µg/L. The average concentration of PO_4^{3-} in the South Campus Well was 15.2 µg/L. NH_4^+ concentration varied for all sampling sites throughout survey. Concentrations of NH_4^+ in the South Oval Well varied significantly from October (380.8 µg/L) to April (850.5 µg/L). Concentrations of NH_4^+ in Mirror Lake ranged from 110.8 µg/L in January to 1682.4 µg/L in April. The Olentangy River showed the smallest range of NH_4^+ (290.3 µg/L to 504.0 µg/L) throughout survey. SiO_2 concentrations in the South Oval Well (12800 µg/L to 14200 µg/L) and Mirror Lake (3720 µg/L to 4160 µg/L) stayed relatively constant throughout survey. The Olentangy River exhibited SiO_2 concentrations that ranged from 2100 µg/L to 6090 µg/L, with the highest concentration being in January, and the smallest concentration being in April.

Isotopic Analysis

The $\delta^{18}O$ and δD data for my samples are plotted with the Global Meteroic Water Line (GMWL) in Figures 9 and 10 (Faure, 1998). The South Oval Well exhibited the least variance in $\delta^{18}O$ isotopic composition of all three sample sites. Ranges of $\delta^{18}O$ isotopic composition for the selected sites were: South Oval Well (-8.29‰ to -5.78‰), Mirror Lake (-9.73‰ to -5.79‰) and the Olentangy River (-9.50‰ to -5.51‰). In January, the Olentangy River showed the lightest isotopic composition out of all sample locations. All but one Mirror Lake data plots below the GMWL. All but one of the Olentangy River samples plot above the GMWL, whereas all the South Oval Well samples plot above the GMWL. The precipitation sample is of significantly lighter isotopic composition than the other samples. All the data plot very close to the GMWL. Both Mirror Lake and the Olentangy River data, but not the groundwater data show large seasonal variations. This indicates that the surface waters reflect the seasonal changes in the stable isotopes of precipitation whereas the groundwater does not. See Figure 11 for summary of general trends in constituent concentrations.

Discussion

Ion and Nutrient Discussion

The enrichment in Ca^{2+} concentrations seen in March and April South Campus Well samples may be the result of the bedrock leaching Ca^{2+} into the groundwater. The enrichment in Ca^{2+} concentrations seen during this time may also be accounted for by Ca^{2+} being incorporated into the groundwater from the unsaturated layer. When topsoil thaws in the spring, surface water is able to infiltrate the thawed topsoil to recharge water table (Winter et al., 1998). Without previous years' data, there is no way to correlate my findings with previous findings for the

South Campus Well. The Ca^{2+} concentration increases from November to May in the Olentangy River may be accounted for by agricultural lime transport from fields to streams due to runoff. The Na^{+} and Cl^{-} concentrations increase from November to March in Mirror Lake and may be explained by the salting of walkways around Mirror Lake. The increase in concentration of Na^{+} and Cl^{-} from November to March in the Olentangy River may be accounted for by the salt used on roadways whose runoff flows into the Olentangy River. The increase in Na^{+} and Cl^{-} was nearly 1:1 molar for the Olentangy River samples. Mirror Lake and South Campus Well samples did not correlate as closely. Previous Olentangy River data exhibit the same trends for Ca^{2+} and Cl^{-} concentration increases in the spring (A Jacobs, K. Welch, W. B. Lyons, unpublished data). Levels of PO_4^{3-} found in Mirror Lake (396 µm/L to 316 µm/L) were higher than the levels of PO_4^{3-} found in either the South Oval Well (8.4 µm/L to 27.7 µm/L) or the Olentangy River (45.7 µm/L to 74.8 µm/L). Animal waste, due to the ducks present, may result in high concentrations of PO_4^{3-}. Previous studies have shown similar levels of PO_4^{3-} in Mirror Lake. Silica concentrations over the course of the study were highest in the South Oval Well (12800 µm/L to 141 µm/L). This finding indicates that these waters have undergone more extensive silicate mineral weathering than the other waters.

Isotopic Discussion

In January, the Olentangy River showed the lightest isotopic composition out of all sample locations. This may be due to isotopically lighter precipitation that flowed into the Olentangy River in the winter, the coldest time of the year. The $^{18}O/^{16}O$ concentration of the South Campus Well and Mirror Lake were not affected as greatly by this winter precipitation. The South Campus Well maintained relatively constant isotopic signature throughout the winter. This may be due to the ground being frozen, thus preventing recharge.

Conclusions

These results suggest the following:

1. The chemical composition of Mirror Lake is different than the ground water, showing that there is little groundwater, Mirror Lake water interaction. This is due to the fact that the lake is filled by domestic water supply rather than natural processes.

2. The Olentangy River composition is influenced by human activities; both agricultural and road deicing as evidenced by the Na^+, Cl^-, and $N\text{-}NO_3^-$ concentrations.

3. The isotopic composition of sampled waters is close to the Meteoric-Water Line; and the isotopic composition of the surface water varies seasonally.

Future Research

Vadose zone water sampling, especially in spring, could indicate if Ca^{2+} increase seen in South Campus Well is due to recharging or water-rock interaction. Vadose zone water sampling in spring may also answer where the P seen in the South Oval Well comes from.

Sampling Mirror Lake more frequently in the spring may address what causes the high N and P concentrations in the lake.

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Figures

Figure 1: Map of Sampling Sites

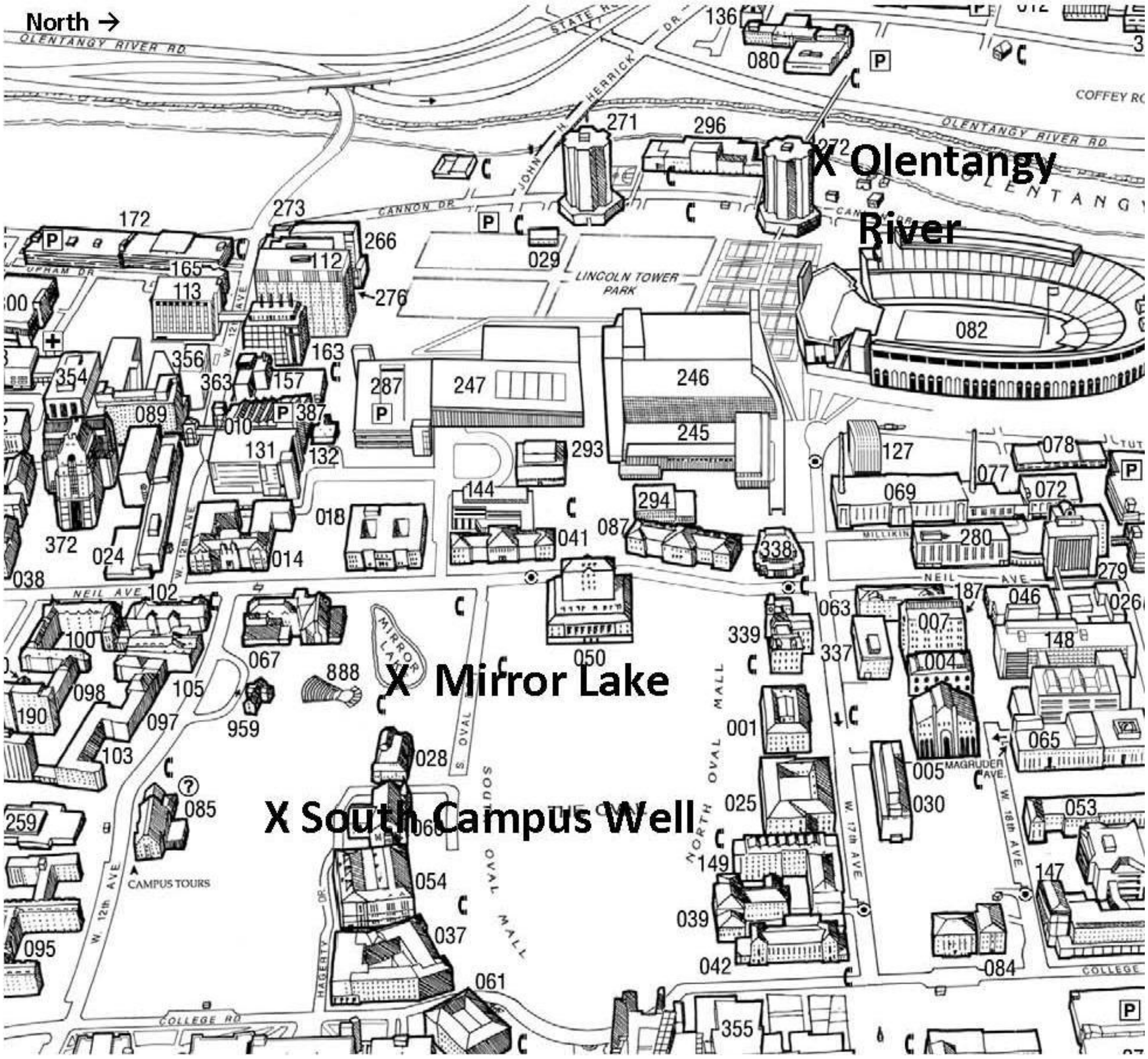


Figure 2: Glacial Map of Ohio

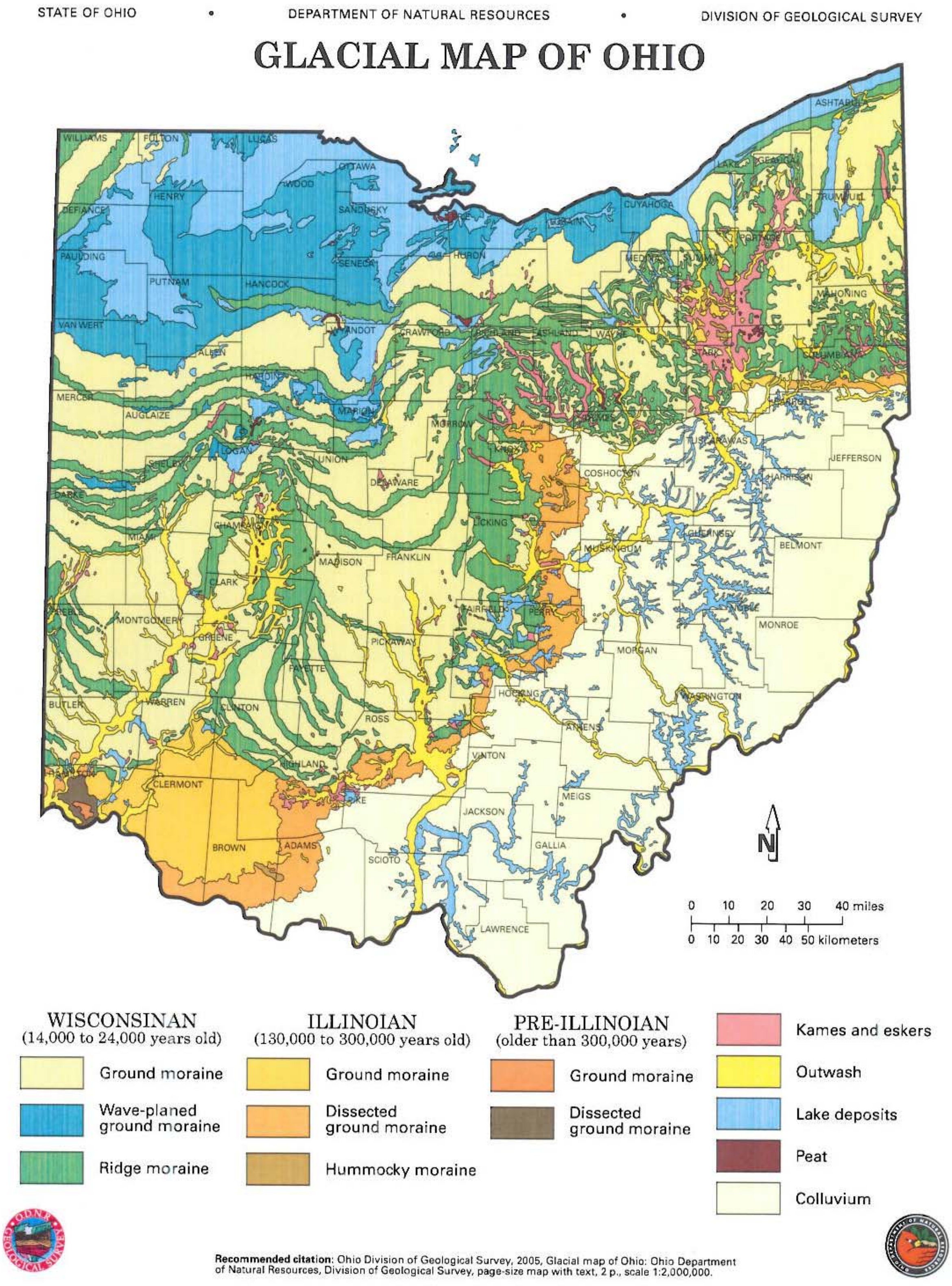


Figure 3: Cross Section of the Carbonate System in Central Ohio

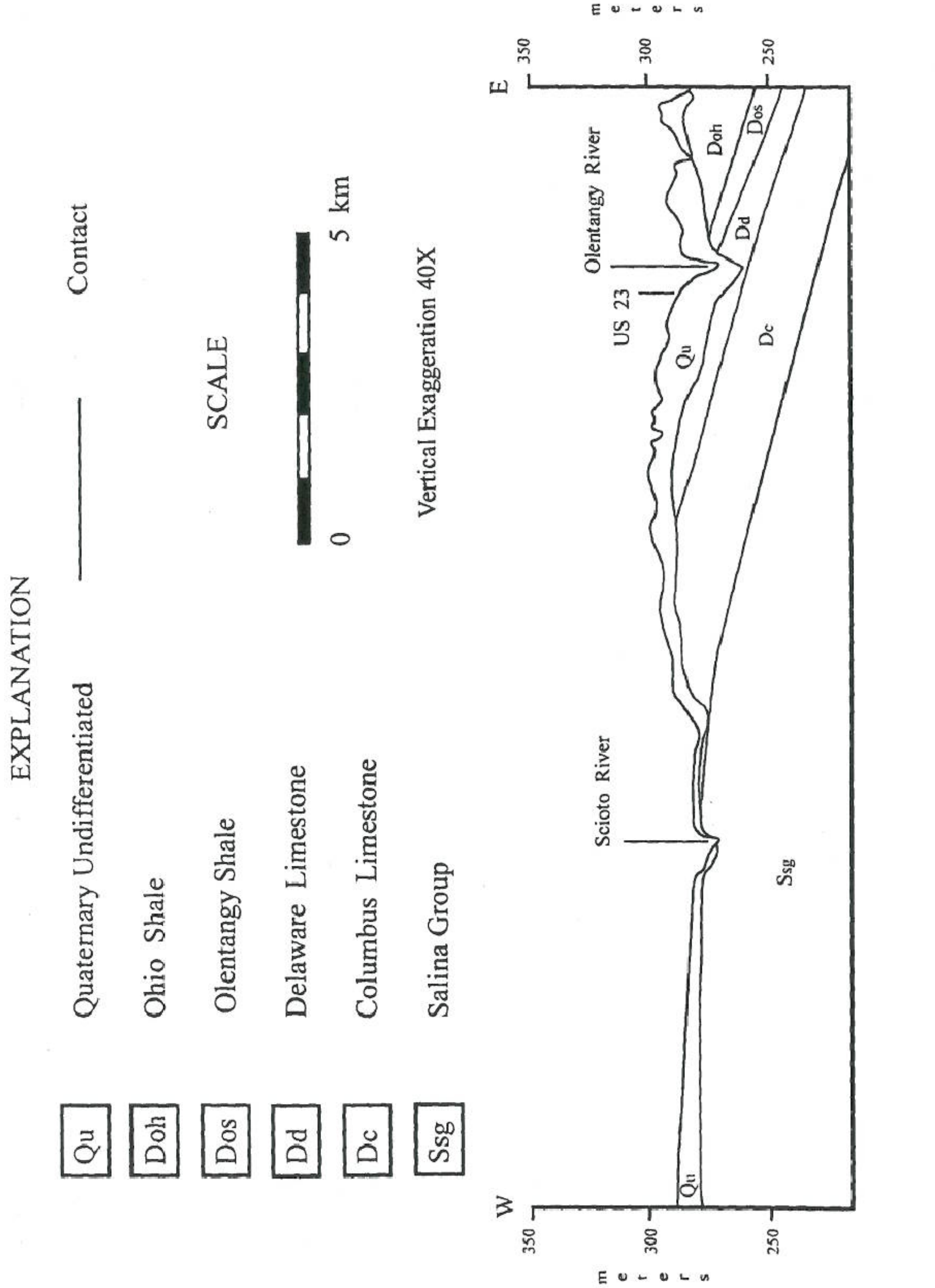


Figure 3. Cross section of the carbonate system adapted from Swinford and Slucher, 1995).

(Friends of the Lower Olentangy, 2005).

Figure 4: Cl-, K+, Ca+, N-NO_3^-, Na+ Concentrations for South Campus Well

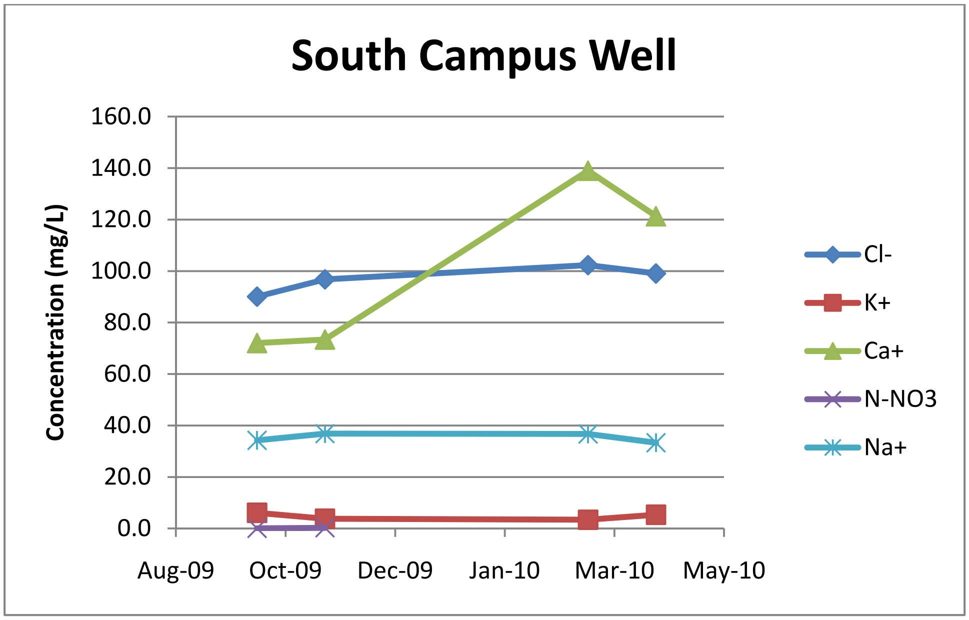


Figure 5: Cl-, K+, Ca+, N-NO_3^-, Na+ Concentrations for Mirror Lake

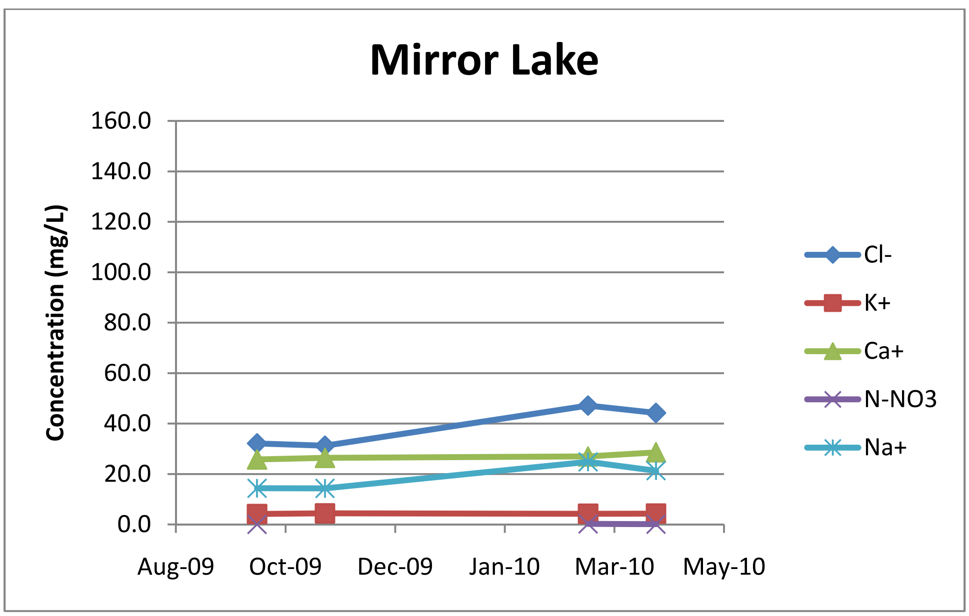


Figure 6: Cl-, K+, Ca+, N-NO_3^-, Na+ Concentrations for the Olentangy River

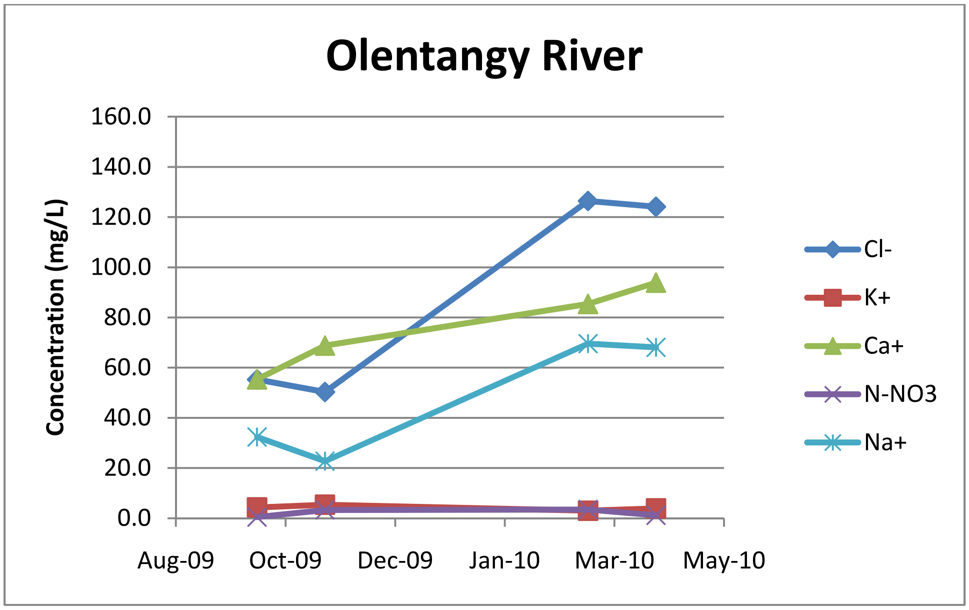
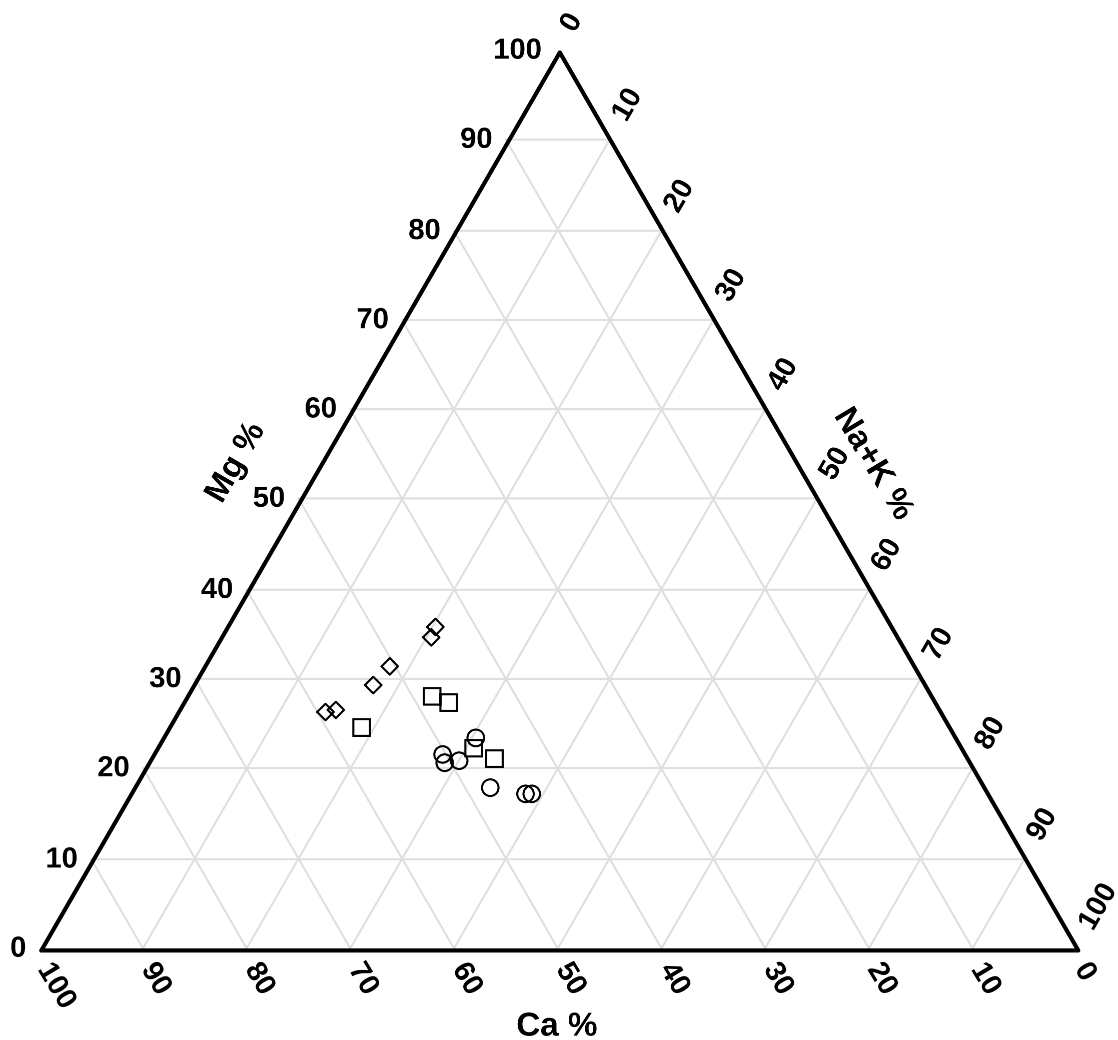
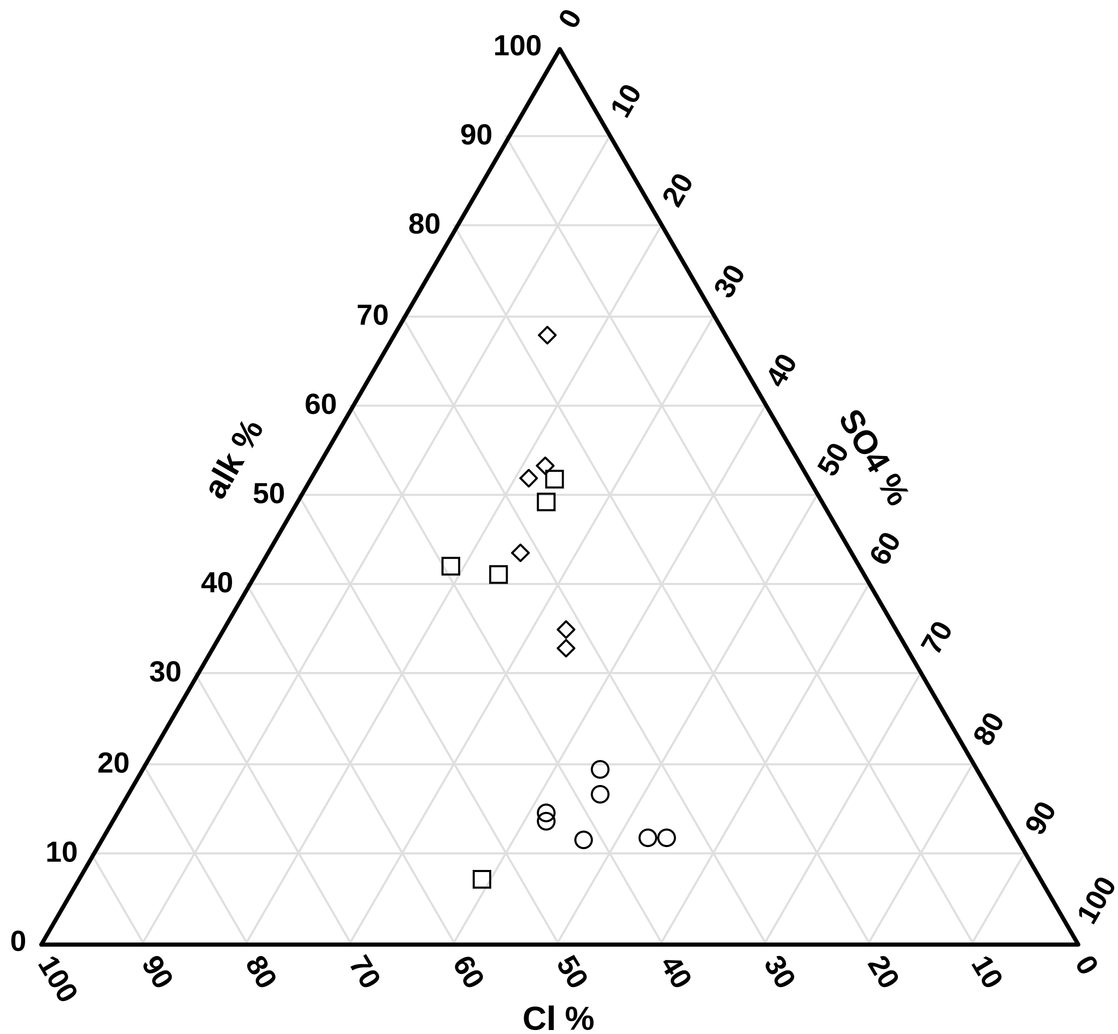


Figure 7: Cation Piper Diagram



South Campus Well - Diamond
Mirror Lake - Circle
Olentangy River - Square

Figure 8: Anion Piper Diagram



South Campus Well - Diamond
Mirror Lake - Circle
Olentangy River - Square

Figure 9: Relationship between δD and $\delta^{18}O$ of Meteoric Precipitation

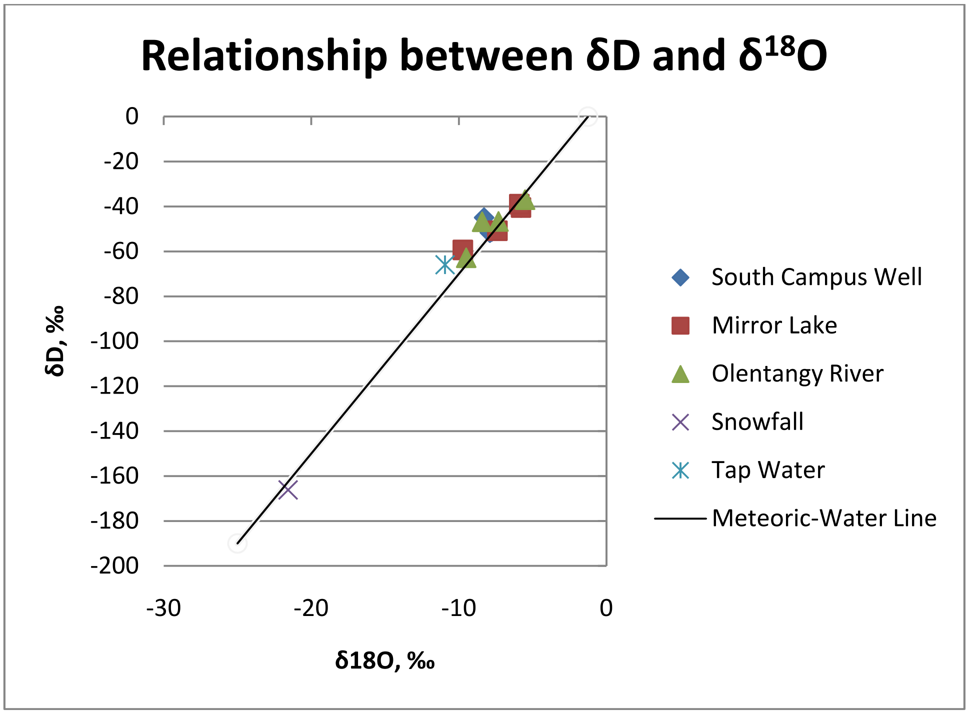


Figure 10: Relationship between δD and $\delta^{18}O$ of Meteoric Precipitation

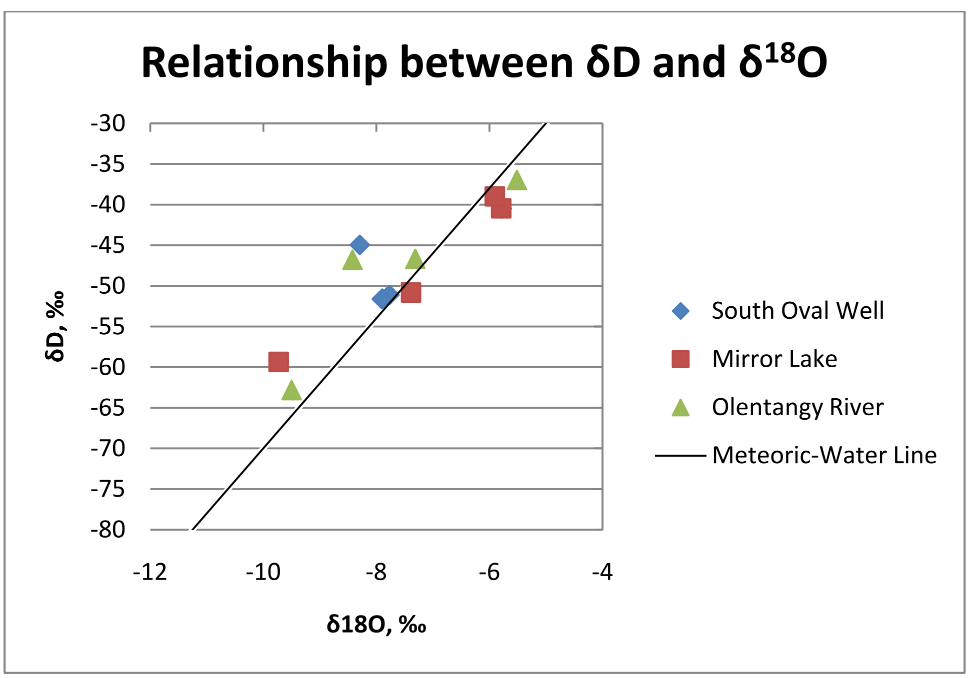


Figure 11: Summary of General Trends in Concentration

Na^+	large increase in Olentangy River in spring
K^+	low concentrations, little seasonal variation
Mg^+	Mirror Lake < Olentangy River < South Campus Well
SO_4^{2-}	Mirror Lake ≈ Olentangy River < South Campus Well (twice as high)
PO_3^-	similar between Olentangy River and South Campus Well, Mirror Lake high
NH_4^+	low concentrations, ML spike in May

Tables

Table 1: Bedrock Formations In The Vicinity Of The Olentangy River

Table 1: Bedrock Formations In The Vicinity Of The Olentangy River			
Formation	**Description**	**Outcrop Area**	**Groundwater Resources**
Mississippian Formations	Soft gray clay shale, resistant massive-bedded sandstone, and black shale overlain by over 100 feet of interbedded gray sandy shales and thin sandstones.	Exposed primarily in the Big Walnut Creek valley in eastern Franklin and Delaware counties and near the source of the Olentangy in Crawford and western Richland counties	Thicker sandstone units (Berea and Black Hand Sandstones) locally productive aquifers; thin sandstone layers, shales, and clays poor sources of groundwater.
Ohio Shale	In excess of 600 feet of hard, brittle, fissile black or brown shale, locally with beds of large (up to 6 ft across) spherical "cannonball" concretions.	Best exposed in ravines and bluffs along the Olentangy River in Franklin and southern Delaware counties.	Poor source of groundwater due to low permeability. Surface water may infiltrate into bedrock along fracture zones and result in springs at contact with underlying Olentangy Shale.
Olentangy Shale	30-35 feet of soft, easily-eroded, blue clay shale and interbedded calcareous shale	Best exposed in ravines and bluffs along the Olentangy River in Franklin and southern Delaware counties.	Poor source of groundwater due to low permeability of the clay shale lithology.
Delaware Limestone	36+ feet of less-resistant, thin-bedded, blue-gray fine-grained limestone and interbedded blue calcareous shale	Best exposed in the Olentangy River valley just east and south of the city of Delaware in southern Delaware County	Mostly poor source of groundwater due to the low permeability of most limestone beds and intervening clay shale layers.
Columbus Limestone	Over 100 feet of ledgy, hard, resistant, gray crystalline limestone, locally cherty, occasionally sandy, with abundant fossils.	Best exposed in quarries and along valley walls along the Scioto River in western Franklin and Delaware counties.	Moderately good aquifer with yields high enough for domestic wells. Water often with high levels of iron.

(Friends of the Lower Olentangy, 2005).

Table 2: Precision of Measurements for Major Ion and Nutrient Data

Table 2. Precision of the major ion and nutrient analytical data is calculated as the average percent difference between duplicate samples. The reporting limit is the lowest concentration that is quantified using our standard methods for each analyte.

	% difference	reporting limit (mg/L)
Major ions		
Cl^-	<1	0.2
SO_4^{2-}	<2	0.2
Na^+	<1	0.2
K^+	<1	0.04
Mg^{2+}	<1	0.1
Ca^{2+}	<1	0.1
Nutrients		
N as NO_3^-	<2	0.003
P as PO_4^{3-}	<3	0.003

(Welch et al., 2010)

Table 3: Precision of Measurements for Major Ion and Nutrient Data Collected

	% difference
Major ions	
Cl^-	0.074
SO_4^{2-}	0.24
Na^+	0.21
K^+	0.23
Mg^{2+}	0.36
Ca^{2+}	0.244
Nutrients	
N as NO_3^-	1.14
P as PO_4^{3-}	ND

Table 4: Precision of Measurements for $\delta^{18}O$ and δD Collected

	‰difference
Isotopes	
$\delta^{18}O$	-1.35
δD	-0.346

Appendix A:

Tabulations of all data

Sample Name	dilution factor	Li mg/L	Li mN	Na mg/L	Na mN
091021 MIRROR	1			14.4	0.62
091119 MIRROR	1	0.004	0.0006	14.3	0.62
100305 MIRROR BLW ICE	1	0.004	0.0006	24.8	1.08
100307 MIRROR	1			23.9	1.04
100411 MIRROR	1			21.3	0.93
091021 OLENTANGY	1	0.006	0.0009	32.3	1.41
091119 OLENTANGY	1 and 5.5	0.007	0.0009	22.7	0.99
100307 OLENTANGY	1 and 5.5	0.006	0.0008	69.5	3.03
100411 OLENTANGY	1 and 5.5	0.009	0.0013	68.1	2.96
091021 S OVAL WELL 1:15	1	0.023	0.0033	34.2	1.49
091119 S CAMPUS WELL	1 and 5.5	0.015	0.0022	36.8	1.60
100307 S OVAL WELL	1 and 10	0.015	0.0021	36.7	1.60
100411 S OVAL WELL	1 and 10	0.016	0.0023	33.3	1.45

Sample Name	K mg/L	K mN	Mg mg/L	Mg mN	Ca mg/L	Ca mN
091021 MIRROR	4.14	0.106	6.5	0.53	25.8	1.29
091119 MIRROR	4.40	0.112	6.9	0.57	26.4	1.32
100305 MIRROR BLW ICE	4.22	0.108	6.4	0.53	27.1	1.35
100307 MIRROR	4.14	0.106	6.3	0.52	26.9	1.34
100411 MIRROR	4.32	0.111	6.5	0.54	28.6	1.43
091021 OLENTANGY	4.32	0.110	19.7	1.62	55.3	2.76
091119 OLENTANGY	5.39	0.138	18.3	1.50	68.8	3.43
100307 OLENTANGY	2.98	0.076	24.0	1.98	85.4	4.26
100411 OLENTANGY	3.93	0.101	27.2	2.24	93.9	4.69
091021 S OVAL WELL 1:15	6.10	0.156	33.7	2.78	72.0	3.59
091119 S CAMPUS WELL	3.78	0.097	36.3	2.99	73.4	3.66
100307 S OVAL WELL	3.38	0.086	37.4	3.08	139.0	6.94
100411 S OVAL WELL	5.35	0.137	33.4	2.75	121.3	6.05

Sample Name	**Analyzed**	**dilution factor**	**F mg/L**	**F mN**	**Cl mg/L**
091021 MIRROR	anion	1	0.552	0.03	32.2
091119 MIRROR	anion	1	0.606	0.03	31.2
100305 MIRROR BLW ICE	100412a	1	0.58	0.03	47.5
100307 MIRROR	100412a	1	0.64	0.03	47.2
100411 MIRROR	100412a	1	0.68	0.04	44.2
091021 OLENTANGY	anion	1			55.3
091119 OLENTANGY	anion	1	0.068	0.00	50.3
100307 OLENTANGY	100412a	1			126.4
100411 OLENTANGY	100412a	1	0.24	0.01	124.1
091021 S OVAL WELL 1:15	anion	1	0.109	0.01	90.1
091119 S CAMPUS WELL	anion	1	0.121	0.01	96.8
100307 S OVAL WELL	100412a	1	0.11	0.01	102.3
100411 S OVAL WELL	100412a	1			99.1

Sample Name	**Cl mN**	**N-NO3 mg/L**	**NO3 mM**	**SO4 mg/L**	**SO4 mN**	**Na+K mN**
091021 MIRROR	0.91	0.019	0.0014	64.7	1.35	0.730
091119 MIRROR	0.88			68.7	1.43	0.735
100305 MIRROR BLW ICE	1.34	0.22	0.0157	60.8	1.27	1.187
100307 MIRROR	1.33	0.10	0.0069	60.3	1.26	1.143
100411 MIRROR	1.25	0.11	0.0081	67.0	1.39	1.038
091021 OLENTANGY	1.56	0.427	0.0305	67.8	1.41	1.517
091119 OLENTANGY	1.42	3.294	0.2352	66.3	1.38	1.126
100307 OLENTANGY	3.57	3.47	0.2474	80.9	1.68	3.101
100411 OLENTANGY	3.50	1.16	0.0831	112.2	2.33	3.062
091021 S OVAL WELL 1:15	2.54	0.055	0.0040	128.6	2.68	1.645
091119 S CAMPUS WELL	2.73	0.026	0.0019	138.1	2.87	1.699
100307 S OVAL WELL	2.89			124.6	2.59	1.684
100411 S OVAL WELL	2.79			105.5	2.20	1.586

Sample Name	**calc alk**	**meas alk mN**
091021 MIRROR	0.30	0.558
091119 MIRROR	0.31	0.563
100305 MIRROR BLW ICE	0.45	0.592
100307 MIRROR	0.41	0.571
100411 MIRROR	0.35	0.567
091021 OLENTANGY	2.90	2.725
091119 OLENTANGY	3.03	2.917
100307 OLENTANGY	3.84	3.113
100411 OLENTANGY	4.07	3.567
091021 S OVAL WELL 1:15	2.80	6.042
091119 S CAMPUS WELL	2.74	no data
100307 S OVAL WELL	6.22	5.788
100411 S OVAL WELL	5.39	4.892

all values In percent equivalencies

Sample Name	Cl^-	SO_4^{2-}	alk	Na+K	Mg	Ca^{2+}
091021 MIRROR	35.6	52.8	11.6	28.6	21.0	50.4
091119 MIRROR	33.6	54.5	11.9	28.0	21.8	50.2
100305 MIRROR BLW ICE	43.7	41.3	14.5	38.7	17.3	44.0
100307 MIRROR	44.4	41.9	13.5	38.1	17.2	44.7
100411 MIRROR	41.5	46.4	11.8	34.6	17.9	47.5
Mean of Mirror Lake Samples	**39.7**	**47.4**	**12.7**	**33.6**	**19.0**	**47.4**
091021 OLENTANGY	26.4	23.9	49.2	25.7	27.5	46.8
091119 OLENTANGY	23.4	22.8	50.0	18.6	24.8	56.6
100307 OLENTANGY	38.2	18.0	41.1	33.2	21.2	45.6
100411 OLENTANGY	35.0	23.4	40.7	30.7	22.4	46.9
Mean of Olentangy Samples	**30.8**	**22.0**	**45.3**	**27.0**	**24.0**	**49.0**
091021 S CAMPUS WELL	31.7	33.4	34.9	20.5	34.6	44.8
091119 S CAMPUS WELL	32.7	34.4	32.9	20.3	35.8	43.9
100307 S CAMPUS WELL	24.7	22.2	53.2	14.4	26.3	59.3
100411 S CAMPUS WELL	26.9	21.1	52.0	15.3	26.4	58.3
Mean of South CAMPUS Well Samples	**29.0**	**27.8**	**43.2**	**17.6**	**30.8**	**51.6**

Date	Location	PO_4^{3-} (µg/L)	NH_4^+ (µg/L)	SiO_2 (µg/L)
100116	South Campus Well	9.80	3801	14200
100118	South Campus Well	8.40	412	14000
100307	South Campus Well	14.9	530	14100
100411	South Campus Well	27.7	851	12800
100118	Mirror Lake	396	111	3720
100305	Mirror Lake	394	212	4000
100307	Mirror Lake	358	245	3950
100411	Mirror Lake	316	1680	4160
100118	Olentangy River	74.8	290	6100
100307	Olentangy River	45.7	457	4650
100411	Olentangy River	53.9	504	2110

X-values delta 18/16O	**delta (hydrogen/deuterium)**	_	**Date**	**Location**
-5.78	-40.48		Oct-09	S. Campus Well 091021 1:15pm
-7.89	-51.57		Nov-09	S. Campus Well 091119
-7.77	-51.12		Jan-10	S. Campus Well 100118
-7.90	-51.63		Jan-10	S. Campus Well 100116
-8.29	-45.0		May-10	S. Campus Well 100520
-5.51	-36.96		Oct-10	Olentangy 091021
-7.31	-46.68		Nov-09	Olentangy 091119
-9.5	-62.83		Jan-10	Olentangy 100118
-8.42	-46.8		May-10	Olentangy100520
-5.79	-40.46		Oct-10	Mirror Lake 091021 1:15pm
-5.90	-38.98		Nov-09	Mirror Lake 091119
-7.39	-50.82		Jan-10	Mirror Lake 101018
-9.73	-59.4		May-10	Mirror Lake 100520
-21.57	-166.19		Feb-10	Snow 100205
-10.94	-65.9		May-10	Byrd Br #20 100521